Earth-Image Tracking in the IR For Deep Space Optical Communications

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Abstract: Sub-microradian level laser beam pointing to an Earth-based receiver is required for deep space optical communications. This requires a beacon emanated from Earth towards the spacecraft. The beacon could be a laser or reflected sunlight from Earth. Earth image tracking in the visible is hampered by significant albedo variations andor crescent Earth image yielding large central errors. Here, we report results of Earth-image tracking in the infrared (8 to 13 micron) region of the spectrum with the aim of substantially alleviating the two challenges mentioned earlier

Introduction

Optical communications from deep space requires laser beam pointing with an accuracy of 10's to 100's of nano-radians. To accomplish this, the acquisition and tracking sensors within the flight lasercom terminal will require a beacon directed to the spacecraft from the vicinity of the Earth-based receiver. One option is to provide a high power laser-beacon to the spacecraft. For a Mars mission with the maximum range to Earth of about 2.5 AU, a laser with approximately 1 kW of average power will be required. As the range increases to 40 AU for planets at the edge of solar system, the required laser power increases to currently unpractical levels. Also, special permits are required for beam propagation through the atmosphere with possible outages at critical communication periods. Laser reliability and lifetime will have to be high to minimize downtime and operations cost. Tracking of the Earth image is an alternative option to laser beacon tracking. Depending on the range to the spacecraft and the Sun-Earth- Spacecraft angle, the Earth image may be a thin crescent, making the image centroiding task more difficult and less accurate. Our earlier analysis on Earth image tracking in the visible region of the spectrum proved useful to the point of meeting the requirements when a full-Earth image was available, and there was sufficient Moonlight for an albedo-variation-free calibration source [1,2]. Occurrences of crescent Earth, Earth's albedo variations, and insufficient Moonlight for outer planetary missions compromised the tracking accuracy. The major limitations with this concept have been a) a low signal level at high Earth phase angles and b) a large albedo variation due to Earth atmospheric changes [3]. An alternative technique, discussed here, is to image the Earth in the infrared (IR) region of the spectrum. A Thermal-IR Earth Tracker can mitigate the difficulties experienced by the laser-beacon-tracking technology and the Visible Earth image-tracking problems. The Thermal-IR imager is expected to provide a full-Earth image at all times anywhere within the solar system, simplifying the Earth-image fitting for precision centroiding. The three main difficulties experienced by the visible tracker: phase dependence, albedo variations, and low signal levels will potentially be overcome by imaging in the thermal-IR. Preliminary analysis indicates that sufficient infrared light is emitted from Earth to track it beyond 40 AU with a 30 cm aperture.

Figure 1. Visible Earth image compared with the thermal image taken at the same distance to Earth

Figure (1) shows a recent (April 21, 2001) image taken by the Mars Odyssey spacecraft from a range of 3.56 million **km.** When observing in the 8-13 micron band, a full Earth thermal image was recorded even for high phase angles, whereas the visible band image shows a thin crescent Earth. Low emissivity variations of thermal images are shown due to the relatively slow thermal changes of the Earth surfaces compared with rapid changes of reflectivity of the Earth surface for visible wavelength. We simulated the effect of a wide range of emissivity variations on the achievable centroiding accuracy. The precise location of the Earth receiver is determined by: (1) computing the Earth's centroid location from the image, and (2) calculating (bias) error in determining the receiver location relative to the center of the Earth based on time information and an on-board model. Modeling and analysis that determine the feasibility and practicality of this approach include: (1) effects of stray light and solar interference in the field-of-view including operation at small (4.5deg) Sun-spacecraft-Earth angles; (2) achievable centroiding accuracy (both jitter and bias); (3) required optics aperture size and the effect of separate apertures vs. a common aperture for both the IR tracker and the lasercom terminal.

Preliminary Analysis Conclusions

Preliminary analysis indicates that a fixed field-of-view (FOV) per pixel imaging system should be able to cover the entire mission range from 0.1 AU to 40 AU. The unblurred Earth image size varies from 850 urad at 0.1 AU to 2 urad at 40 AU range. The Earth image size variations will not affect IR detector performance provided FOV per pixel and update rate are limited within certain ranges for each telescope aperture size (10-50 cm). Noise equivalent angle (NEA) and bias error will vary as the Earth image size changes during a mission, but are confined to within the allocated pointing loss budget (assumed 2 dB of pointing loss). Therefore, the effect of Earth image size variations on the required optics system design is minimal.

Table (1) summarizes the operable IR camera update rates and FOV-per-pixel for meeting an assumed 2 dB of pointing loss allocation. The calculated maximum bias error, NEA and downlink beam full-width-at-half-maximum (FWHM) at the wavelength of 1064nm is also summarized in this table.

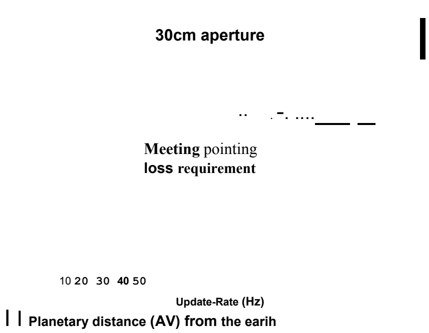

Figure 2a Figure 2b Figure 2a shows the range of operable FOV per pixel as a function of update rate for a 30-cm aperture. The FOVIpixel increases with decreasing IR camera update rate. Figure 2b shows the estimated thermal IR signal levels over the solar system range.

References:

[I] H. Tsou, T. Y. Yan, "Maximum likelihood based extended-source spatial ATP.. .", SPIE Val. 3615, pp. 214-221 (1999).
[2] G. G. Ortiz, S. Lee, "Earth LWIR tracker for deep space optical comm.,:, LEOS 2004, Arizona
[3] C. C. Chen, "Effect of Earth Albedo Variation on the Performance of a Spatial Acquisition.. .",*JPL TDAProgress Report 42-95,* 1988.

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